BEFORE THE
DEPARTMENT OF COMMERCE

In the Matter of	)	
	)	
Federal Communications Commission	)	GN Docket No. 12-354
	)	
Amendment of the Commission's Rules	)	
with Regard to Commercial Operations in	)	
the 3550-3650 MHz Band	)	

Comments of Allied Communications, LLC

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1 Executive Summary

Allied Communications LLC is a subsidiary of Allied Minds Federal Innovations (AMFI) founded in 2012 by globally recognized technology leaders to commercialize mobile broadband technologies to enhance user quality of experience and improve subscriber loyalty while reducing capital expenses and operating costs. Technologies emphasize the use of cognitive radio approaches to network resource management.

Allied Communications is dedicated to the acceleration of the affordable deployment of 3GPP Long Term Evolution (LTE) and to leveraging LTE technology for the public good, such as for first responders. We respond to the FCC's request for comments on the Citizens Broadband Service (CBS) *Notice* to help to unleash broadband opportunities for consumers throughout the country, particularly in areas with overburdened spectrum resources. Allied Communications appreciates the opportunity to respond to your request for specific comments on costs and benefits of specific rules in this *Notice, 12-148,* for spectrum sharing in the 3550-3650 MHz band.

We fully support the CBS strategy and offer our comments for rule-making that will enhance benefits to society while protecting private investments and US military capabilities. The overall FCC approach of creating a CBS in the 3550 MHz band and generally allowing low-power commercial small cells, along with a coordinated process involving databases and other methods, such as spectrum sensing, for supporting higher-power commercial applications consistent with President's Council of Advisors on Science and Technology (PCAST)[1] recommendations cited at paragraph 89 of the *Notice* could be a major advance in spectrum policy. However, specific CBS rules should, we believe, be adjusted from that of the NPRM to reflect the following major points of our response:

1. excessive exclusion zones of the NTIA in the *Notice* can be mitigated without causing harmful interference via insightful rule making;

2. interference is asymmetric and dynamic, so Spectrum Access Systems (SAS) rules need to be enhanced over the Television White Space (TVWS) approach;

3. temporal sharing and closed-loop control enabled by the tiered approach may increase the value of the CBS if rule-making allow and encourage fine timescales as an SAS parameter with CBS device feedback closing the control loop; and

4. sharing of military-related bands requires specific information privacy and security rules.

2 Introduction

Allied Communications' four major points address costs and benefits of FCC rule making alternatives. We emphasize technology commercialization opportunities and challenges, within a framework that would protect private investment, expand CBS product markets, and protect sensitive military information without undue burden on commercialization. In addition, products and services in the 3550 MHz band, especially those derived from LTE technology, may significantly enhance the Government's FirstNet capability in the 700 MHz Public Safety Band Class 14 (includes D block) with FirstNet able to leverage the 3550 MHz CBS shared spectrum for first responders for broadband surge capacity. The benefits of such opportunistic leveraging are particularly clear in major contingencies like Hurricane Katrina or Super Storm Sandy where National Guard and military units augment first responders, placing a significant burden on radio spectrum before, during, and after such an incident.

Globally, FCC leadership in the 3550 MHz band could be a catalyst for global adoption of 3550 MHz databases, information protection, traffic prioritization, and spectrum sharing that would provide host nation policy control while enabling non-governmental first responders (e.g. Red Cross and Red Crescent) to work more effectively with civil, commercial, and military units of host nation and responding nations so that policy decisions may be implemented in seconds to minutes, saving lives, versus the hours to days or in some cases weeks that it took in the

[1] PCAST, Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth (rel. July 20, 2012) (PCAST Report)

Indonesian Tsunami, for example. Thus, the benefits to society of 3500 MHz rule making could be truly significant.

The balance of this introduction highlights the technical, business, and legal issues addressed in our recommendations for insightful rule making, emphasizing the four key topics of exclusion zones, interference asymmetry, fine scale temporal resolution for closed loop control, and information security, with highlights as follows.

2.1 Rules Defining Exclusion Zones

We show evidence that the NTIA survey's fast track map of exclusion zones is excessively conservative. Interference-to-Noise (I/N) metrics of *Notice* paragraph 115 ranging from -6 dB to -10 dB[2] assume an environment where incumbent systems have no tolerance for interference, which, by and large, is not the case and more importantly need not be the case going forward. Below we present evidence supporting the FCC at paragraph 116 that incumbent use zones be based on interference of commercial systems to military systems.

Military systems are known to be designed to operate in harsh electromagnetic environments, with degrees of interference many orders of magnitude more severe than CBS operations. Resistance to interference increases with every new generation of military technology.

The impact on radio propagation of terrain in rural settings and of obstructions in dense, urban areas should be reflected in FCC rules for CBS exclusion zones. Measurements and more accurate RF propagation models reveal substantially smaller geographic exclusion zones that significantly extend opportunities for secondary spectrum access and sharing, growing markets accordingly.

Allied Communications suggests rules promoting a hybrid architecture that leverages both a database and spectrum sensing. The cost of reducing exclusion zones by employing spectrum sensing in SAS would be small, comparable to one stage of Wi-Fi evolution, while the directly resulting benefits include extending CBS to 95% of the population of the US, driving equipment prices down because of a broader market with Wi-Fi potential, fostering global adoption of similar policies, attracting investment in US-led innovations, thus creating jobs, and substantially enhancing the benefit to society that the FCC seeks.

2.2 Rules Reflecting Interference Asymmetry

While there has been significant emphasis on cellular systems interfering with radar platforms, given the highly asymmetric transmit powers and antenna gain, cellular systems invariably experience greater interference from radar systems than radar systems experience from cellular systems as noted in the *Notice* at paragraph 59. Allied Communications recommends that FCC rule-making leverage the benefits of this physical asymmetry for CBS SAS.

[2] "Interference Protection Criteria", NTIA Report 05-432, October 2005.

2.3 Rules Enabling Temporal Sharing and Closed Loop Control

Responding to *Notice* paragraphs 64-68, rules requiring sensing and reporting in CBS devices and database integration in SAS present a unique opportunity for SAS to implement a closed-loop system for dynamic spectrum access enabling effective spatial and temporal interference management for sharing of spectrum. Such a schema mitigates adjacent channel interference (ACI) of the sort encountered in LightSquared and GPS devices. Closed-loop SAS dynamically adjusts spatial, spectral, and temporal boundaries in accordance with signal measurements and certified autonomous complaints to SAS from computationally intelligent CBS devices. Previous approaches based solely on sensing[3] or databases[4] lack the closed-loop control which prevents them from adapting and evolving to mutual interference conditions.

Temporal sharing includes short, medium, and long timescales, depending on the temporal dynamics of the electromagnetic systems involved, their purposes and missions, and their mobility patterns. Rules enabling temporal sharing enabled by spectrum sensing and reporting by mobile devices using methods comparable to LTE's minimize drive testing (MDT) feature would increase market size conservatively estimated as by a factor of two, resulting in a peak data rate increase as estimated below of a factor of 24 above the restrictive exclusion zones of the *Notice* without introducing harmful interference and in fact mitigating unexpected interference via closed loop feedback control within the places and times of such interference, achieving benefits on control-loop time scales of microseconds to seconds vs. on litigation time scales of months to years. Thus protection via closed loop time-based and direction-based SAS would excel for radar and Fixed Satellite System (FSS) incumbents cited above.

2.4 Information Security

The database approach used in the TV whitespace bands is not well suited for use in military bands. Allowing open querying of near-real-time military spectrum plans may allow a malicious agent to gain compromising information, enabling interference with federal law enforcement or military operations. Instead, a SAS database should accept requests for spectrum usage and enable frequency band usage as a function of service priority, location, time, and frequency based on the database's internal knowledge of governmental spectrum reservations and usage without revealing potentially compromising details of that usage to an unauthorized third party, either directly or indirectly.

The SAS database should use a variety of techniques including access controls and obfuscation to make it difficult for a malicious agent to acquire operationally compromising information. The CBS rule making should specify that SAS databases may be accessible only in authorized modes (e.g. limiting query responses) by authorized entities that may include a cognitive query capability for the General Authorized Access (GAA) devices of the *Notice* as well as certified commercial operators. The CBS rule making may specify a requirement for SAS audit trails with automatic analysis of audit trails to alert federal state, and local law enforcement and

[3] "Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) devices in the 5 GHz band", FCC Report and Order, ET Docket No. 03-122, November 2003.
[4] "Unlicensed Operation in the TV Broadcast Bands", FCC Third Memorandum Opinion and Order, ET Docket No. 04-186, April 2012.

military organizations to potential compromises. In addition, there may be legal ramifications of including military information in SAS related to the US espionage statutes (US Title 18) requiring the protection of sensitive military information; our recommendations on this topic provided below would enable the FCC's rules to realize protection without unnecessarily inhibiting commercial development of the 3550 MHz band.

3 Spectrum Sharing Architecture Recommendations

Allied Communications supports a tiered licensing approach using a spectrum database concept at paragraph 95, with a variety of operational and security improvements; and relying on geolocation capabilities at paragraph 96. However there are a few recommended architectural recommendations to better address the needs of the incumbents from both an interference mitigation perspective but also a security perspective.

3.1 Current Sharing Architecture Proposals

There are many similarities between the FCC proposed spectrum sharing plan, the Spectrum Access System (SAS) outlined in the PCAST proposal, and the Authorized Shared Access (ASA) proposal put forth by Qualcomm and Nokia. All three approaches provide for legacy users to be able to remain and operate in their current bands; all utilize database access; all recognize that perhaps there might be a role for sensing techniques (although such use is vague at this time).

The FCC plan is similar to the PCAST plan in that both employ three tiers of users: (i) Federal Primary Access (PCAST) or Incumbent Access (FCC). (ii) Secondary Access (PCAST) or Priority Access (FCC), (iii) General Authorized Access (PCAST and FCC). The ASA proposal allows for two tiers of users: (i) Incumbent Users and (ii) ASA Licensee. All three define the legacy uses as having ultimate access. The FCC and ASA approaches are similar in that spectrum not occupied by legacy users would be delegated to the Priority Access users or ASA Licensees. The SAS and FCC approaches are similar in that General Authorized Access users can use the spectrum when legacy users are not, though authorization by a database.

One would expect that GAA users to be similar to unlicensed users today who do not have guarantees of interference protection. For SAS, secondary access users would have priority over GAA users in all cases. ASA does not allow for this provision and furthermore only 3G and 4G cellular devices are allowed to use the unoccupied band.

3.2 Instantiating Proposed Sharing Architecture

The approaches described in the previous section are all conceptual in their treatment of different user classes, but the proposals to date lack specific approaches to implementation. These details have a major impact on the performance and security of the ultimate system.

The current TVWS database architecture is ill-suited for adaptation to federal spectrum sharing, and should not be used as the basis for implementing any of the proposed sharing architectures. First, it lacks the ability to directly leverage spectrum sensing, and therefore it is unable to apply ground-truth measurements in fine-tuning its propagation models, and must assume the worst propagation. Second, it lacks the ability to handle temporal information because digital television signals are assumed to be always transmitting, making it unable to support temporal sharing between commercial and federal systems. Third, it is an open book giving a malicious entity the ability to map federal spectrum use as a part of a potential jamming or disruption campaign.

The current interaction between a secondary user and the existing TVWS database architecture enables opportunities to learn behavioral information on the incumbent users through the query process. Additionally, shared use in the 3550-3650MHz band, while similar to TVWS, is fundamentally more challenging warranting alternate architectures for database interaction. Allied Communications suggests a hybrid architecture that leverages both a database and spectrum sensing, and that the proposed database should support obfuscation of sensitive data.

3.3 Recommended Sharing Architecture

The following sections detail the recommended sharing architecture.

3.3.1 Core Features

Allied Communications recommends that the proposed sharing architecture incorporate the following core features.

1. The system should have multiple tiers of service, including incumbents (tier 1) and licensed secondary users (tier 2).

2. Unlicensed users may be supported as the lowest priority (tier 3), depending on the frequency band to which the database is applied. The 3550 MHz band may not be the optimal band for initially supporting unlicensed users, who should generally only be supported in bands where incumbent systems have a sufficient level of interference tolerance. Given the heterogeneity of legacy users in the 3550 MHz band this could prove difficult in the near term.

3. Licensed secondary users seeking a spectrum lease should make a request for spectrum to a CBS spectrum sharing database (CSDB). The CSDB has knowledge of the temporal, spatial, and spectral use of the incumbent systems and tracks leases provided to licensed secondary users. It uses detailed terrain and propagation models to identify available bands satisfying the lease request. If any such bands are available it then issues the lease to the requesting licensed secondary user for one of the bands.

4. Licensed secondary users should receive time-bound leases that cover a particular frequency in a particular geographic region. These leases must be revocable by the CSDB at any time.

5. Leases granted to licensed secondary users *may* or *may not* require sensing. Leases not requiring sensing would be appropriate for leases granted in regions where incumbent use is fixed with a high duty cycle, such as fixed line-of-sight microwave incumbents. Leases requiring sensing would be appropriate for leases granted in regions where incumbent use is mobile or temporally dynamic, such as radar. By issuing a lease that requires sensing, a large geographic exclusion zone is not required to account for the potential use of the band by a highly mobile or temporally dynamic system.

6. The architecture should aggregate some level of sensing reports from licensed secondary users, who can act as a distributed network of RF sensors enabling the improvement of the terrain and propagation models used by the CSDB based on ground-truth measurements.

7. The CSDB should respond to general spectrum requests, e.g. a request for any 10 MHz segment anywhere within a 100 MHz band, rather than allow third parties to query all incumbent and licensed secondary user records to make its own determination as to available bands. This makes it more difficult for a malicious entity to reverse-engineer potentially sensitive incumbent activity, and allows implementation of a broad range of operational security countermeasures in selecting frequency bands for lease assignments.

The combination of sensing and databases in this approach has a number of unique ramifications. First, it creates a closed-loop control system with inputs, decisions, outputs, and feedback. This is fundamentally different from previous approaches that relied only on sensing (e.g. Dynamic Frequency Selection) or databases (e.g. TVWS). The ability to incorporate feedback allows one to change the decision logic over time and tune the system parameters to achieve much greater levels of coexistence. For example, I/N requirements could be updated based on observed mission impact rather than the conservative, analytical, model-driven approaches used today.

3.3.2 Rules for a Citizens Spectrum-sharing Database (CSDB)

Protected CSCB tiers should include reservations, usage, observations, complaints, and a reconciliation audit trail. SAS rules should mandate regular reporting of usage, complaints, and reconciliation actions to public safety, military, and commercial spectrum managers, while equipment manufacturers and network operators would be allowed to access vendor-specific information in real time.

We propose that the rule making for SAS mandate a public applications programmer interface (API) enabling open source, open access spectrum awareness applications for such databases. We recommend that SAS-CSDB include associated non-public (commercial, first responder, and military) applications and licenses extending the public API for commercial for-profit usage. An open commercial protocol such as PAWS[5] may be employed to access CSDB securely via a hierarchy of device types including master devices having geolocation capability and slave devices having no geolocation or direct CSCB access, but operating under the control of a master device.

We recommend that the FCC empower device manufacturers to adapt standards to CBS small cell usage. We further recommend that the SAS-CSDB enable registration of band-channel-mode combinations reflecting heterogeneous systems as the needs of the community may dictate.

We recommend that UE including consumer purchased small cells be configurable by the consumer to allow a wireless service provider to operate CBS equipment as part of the network;

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[5] V. Chen, et al, "Protocol to Access Spectrum Database", IETF Internet Draft, February 2013, available from http://tools.ietf.org/html/draft-ietf-paws-protocol.

and that the SAS CSDB reflect the operator's air interface and signal in space configuration while protecting proprietary deployment information of a service provider.

3.3.3 Rules for RSSI and RSCI Reporting

We recommend that CBS rules require the regular reporting to SAS CSDB of received signal strength indication (RSSI) and received signal classification indication (RSCI) of co-channel and adjacent channel signals that may be detected and classified as contributing to RSSI above a noise threshold. The LTE advanced standard for MDT illustrates the benefits and technical features of such measurement and reporting schema and is recommended to the FCC as a model for rule-making.

The capabilities for CBS RSSI should include automatic gain control (AGC) capture event reporting as is typical when a high-powered radar illuminates a communications receiver. The capabilities for CBS RSCI should include the recognition and reporting of technical features (not signal types per se, but technical features) of incumbent, priority, and GAA signals that exist or that may exist. It would be inappropriate for UE or small cell to be able determine via malicious use of the CSDB information such as "FBI (radio) is now at the corner of First Avenue and Main Street." However, the reporting of a vector of signal features to a tiered access CSDB would enable authorized entities to establish space-time contours of federal incumbent usage to protect these users. RSSI and RSCI reporting at a given location and time will allow protected tiers of CSDB to map the transmissions of incumbents, priority users, and GAA users in space, time, and frequency.

3.3.4 Rules for Dynamic Exclusion Contours

With Allied Communications recommended rules for RSSI and RSCI reporting, the exclusion zones for the top tier of the three tiered approach need not exclude 60% of the population as is the case with *Notice* Figure 2 at paragraph 117, but may bring 3550 MHz small cell products and services to most of the population most of the time. Therefore, access to the full CSDB would need to be limited to authorized entities as recommended further below.

Allied Communications recommends that rules for dynamic exclusion contours take into account the ability of contemporary wireless networks to tolerate impulsive interference. Consequently, dynamic exclusion contours would protect incumbent radar (Notice III.C.2.a) and FSS (Notice III.C.2.b), but would allow impulsive noise from protected incumbents (such as pulse radars) into the space-time contours of priority and GAA users.

3.3.5 Rules for Improved Protection of Military Incumbents

Protection contours defined dynamically by such an enhanced CSDB in space, time, and radio frequency, may protect incumbent military users with significantly greater protection than the exclusion zones of the Notice. Such dynamic contours of a CSDB realization of SAS may reduce the degree to which existing military radar systems would need to be modified or enhanced in order to continue to provide required military capabilities.

4 Measurement Campaign and Analysis

Exclusion zone for incumbent access in its current form in the *Notice* at Fig. 2 would exclude more than 60% of the population of the United States almost all of the time, hence limiting the commercial market for a Citizens Broadband Service (CBS) to 40% of the population. Rules recommended by Allied Communications for SAS would extend the database to include closed-loop spectrum measurement, validation of propagation predictions, and real-time adjustment of first, second, and third tier exclusion zones as a function of observed usage. The feasibility of this approach is based in part on measurements in the 3-4 GHz band presented in this section.

Specifically, Allied Communications would like to comment on the *Notice* at paragraph 8 regarding the provision that "Citizens Broadband Service users would not be permitted to operate within geographically designated Incumbent Use Zones, which would encompass the geographic area where low-powered small cells could cause harmful interference to incumbent operations." More specifically, the NTIA Fast Track report paraphrased by the FCC *Notice* at paragraph 18 states "NTIA's recommendation with regard to the 3.5 GHz Band included significant geographic restrictions to protect existing DoD radar and FSS operations and to protect new commercial systems from co-channel interference from high-powered military in-band shipborne and adjacent band DoD ground-based radar systems. The radar systems that operate in the 3.5 GHz Band overcome the inherent limitations due to increased propagation losses by employing high transmitter power levels and high-gain antennas. These characteristics of the radar systems were a contributing factor to the size of the exclusion zones in the Fast Track evaluation." Our basis for comments includes the analysis of signal strength measurements reported in this paragraph as well as WiMAX interference and related measurement campaigns reported in the technical literature[6].

In order to better quantify the potential for harmful interference to incumbents by RF transmissions in the 3550 MHz band, Allied Communications is cooperating with Virginia Tech in the acquisition and analysis of RF instrumentation measurements in the 3-4 GHz bands. Measurements reported in this section enable more detailed analysis of the exact nature of beneficial CBS usage, such as via the employment of the 3GPP LTE standard in that band. This does not exclude the possibility of Wi-Fi and WiMAX adaptations to the 3550 or 3650 MHz bands. Allied Communications offers our independent analysis of Virginia Tech's measurements of signal strength of Figure 1 for consideration.

4.1 Signal Generation

According to Virginia Tech researchers, a signal generator radiating into an omnidirectional antenna produced a continuous wave sinusoid at 3395 MHz with effective radiated power of 4.3 Watts from the roof of Durham Hall, 1145 Perry Street, Blacksburg, VA, the four story building shown in Figure 2.

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[6] Valcarce, Zhang, "Empirical Indoor-to-Outdoor Propagation Model for Residential Areas at 0.9–3.5 GHz", *IEEE Antennas And Wireless Propagation Letters*, September 2010.

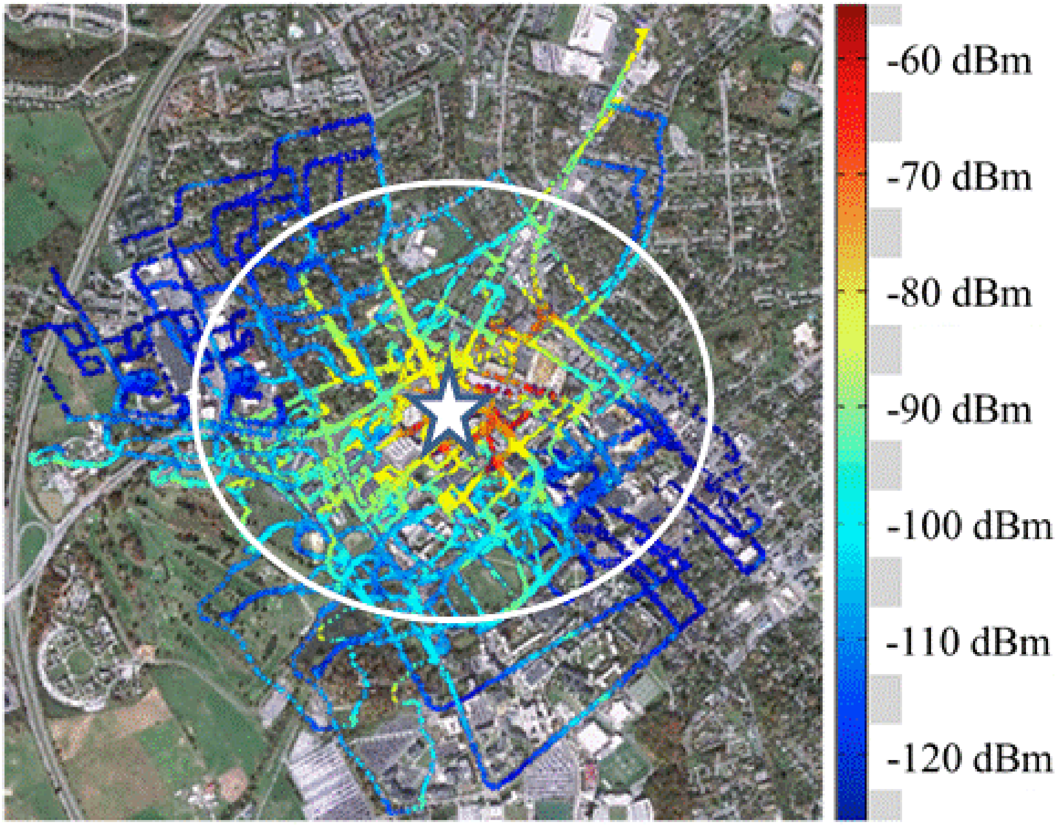

Figure 1 RSSI Heat Map at 3.395 GHz in Blacksburg, VA
Images Copyright © 2012-2013, Google and Virginia Tech

4.2 RSSI Heat Map

A calibrated mobile instrumentation receiver with an equivalent noise bandwidth of 1 kHz was moved by bicycle (in a backpack) along the sidewalks and by automobile along the streets in the vicinity of Durham Hall. Receive antenna height in both cases was 1.5 to 2 meters. Observers note that Durham Hall was typically not within visual line of sight (LoS) when measurements were taken because of buildings or vegetation. Of 3000 measurements, approximately 300 exhibited radio-LoS characteristics. Calibration of measurements yielded the received signal strength heat map of Figure 1.

In the heat map, the location of Durham Hall is indicated by the star, while a radial distance of 1 km is illustrated by the white circle. The received signal strength indication (RSSI) of the dark blue color of the heat map corresponds to calibrated signal strength within a few dB of thermal noise (kTB) of -123 dBm per kHz. One may define harmful interference as interference that causes a communications signal to no longer be able to detect and correct errors without reducing data rate. Modern forward error control (FEC) air interfaces like LTE correct bitstreams without error given 3dB of noise-like interference. Thus a 3dB effective noise level increase from the thermal noise limit of -123 dBm/kHz raises the noise power to -120 dBm and would not constitute harmful to an LTE signal in space.

4.3 Test Environment

A street view of the building itself, the view from the antenna site on the roof (provided by and © Virginia Tech), and a street level view of the surrounding community are shown in the Figure 2. The height of the omni-directional transmitting antenna on the roof of Durham Hall was 45 feet above street level in the rear of the building for a line of sight (LoS) view of much of Blacksburg, VA.

Figure 2 Durham Hall, Rooftop Transmitting Antenna Site, and Vicinity of Tests

Vegetation, low buildings, and utility structures shown in the lower right corner of Figure 2 absorb and shadow street level signals in the 3.4 GHz band. In addition, non-line of sight (NLoS) propagation in the vicinity of buildings, utility poles and power lines produces complex high order Fresnel zones that disperse the RF transmissions.

4.4 LTE Equivalent Signal Strength Projections

The 3GPP LTE standard has emerged as the de-facto migration path for commercial wireless systems. The FirstNet initiative for a US national broadband network for first responders in the 700 MHz Band Class 14 also is embracing LTE. LTE represents the world's largest market for infrastructure and mobile devices. LTE has been adopted by major US wireless network operators including Verizon, ATT, and Sprint. Thus, it is crucial for CBS rulemaking to take into account the relevant technical features of LTE as well as the potential leverage of CBS small cells with commercial and first-responder LTE markets.

The RSSI intensity per kHz of Figure 1 corresponds to the intensity of a single, unmodulated OFDM sub-carrier of an LTE signal, e.g. at a cell site, termed an eNode B or eNB in LTE, sited on the roof of Durham Hall. In an LTE signal that occupies 10 MHz, however, there may be 600 such carriers spaced 15 kHz apart in groups of twelve called resource blocks (RB), resulting in an equivalent LTE small cell power of 2559 Watts. Reducing transmitted power by 10 dB while increasing directional gain would result in a directionally focused small cell with 256 W of radiated power. In other words, the heat map of Figure 1 corresponds closely to an LTE small cell signal of significant total radiated power in each 10 MHz CBS channel between 3.5 and 3.7

GHz. A power level of 1 to 20 Watts would be typical of a small cell, so the heat map of Figure 1 may be conservative. In response to a small cell of Figure 1, user equipment (UE) would radiate responses with power levels of 200 mW (23 dBm), distributed across OFDM carriers for distant signal levels 10 to 30 dB less than the cell downlink characterized above. Thus, the cell site itself offers the greatest potential for harmful interference compared to its client mobile devices.

4.5 Economic Value of Small Cell Outdoor Propagation

Considering Figure 1 further, the majority of the signal propagation does not exceed -80dBm received signal strength indication (RSSI) outside of a 1 km radius from Durham Hall, representing a fourth-law radiation pattern (best fit proportional to $1/r^{3.8}$). In addition, signal strength between -90 and -110 dBm reaches opportunistically to the west and south of the circle along streets and bicycle paths, but not to the southwest, northwest, or southeast. This limited pattern of radiation at a distance is characteristic of the 3550 MHz band. This is important in projecting the economic benefits of CBS. Small cell omni-directional propagation from an omnidirectional antenna on a rooftop represents both worst-case and best case siting.

Outdoor siting is best case in the ability of the transmitting antenna to illuminate the surrounding suburbs. Outdoor siting of a CBS small cell, e.g. at Durham Hall would create new spectrum capacity of ten 10 MHz LTE cells in the 3550 to 3650 MHz band with a range of 1 km. Although appropriate for experimentation, operational usage of CBS small cells would more likely consist of four directional antennas on the roof top, connected to fiber optic infrastructure. Each 10 MHz LTE channel with 600 carriers can provide peak data rate of 6 bps per carrier per millisecond or 3.6 Mbps for an additional 36 Mbps per sector or over 100 Mbps within 1 km of an outdoor small cell. Comparing the 1 km radius of significant radiated energy measured to the 4 km radius predicted by the ideal inverse square law, i.e., $(\lambda/4\pi r)^2$, yields an improvement in realized capacity of 16:1 in subscriber packing density for CBS outdoor small cells.

Note that particularly in the urban and suburban areas along the US coastline most affected by the NTIA exclusion zones, cellular capacity is most limited by user density and load, and not signal-to-noise ratio. Mobile broadband users typically have plenty of “bars,” but compete with other users for available capacity, so sacrificing a small amount of cellular link budget to open up additional bands of operation is a worthy tradeoff.

4.6 Potential for Harmful Outdoor Interference

Outdoor siting on the roof of Durham Hall also is worst-case (compared to indoor siting) in its ability to generate interference at a distance. Specifically, one may observe opportunistic line of sight (LoS) propagation along Main Street to the northeast as shown in the yellow of the heat map outside of the white circle. Considering the possible placement of the small cell in other locations, one may characterize outdoor small cell interference potential. In a location within several km of an incumbent FSS having high gain along Main Street, there could be significant interference from an omnidirectional small cell. In addition, incumbent ship-borne radar illuminating from an elevated position along that direction may receive the CBS energy causing hot clutter, returns with unexpectedly high Doppler shift. An airborne military radar would receive such signal as a function of antenna pointing and aircraft elevation, with radio line of sight extending 200 miles for a high altitude airborne platform. In addition, interference could occur to CBS users in an adjacent cell.

4.7 Limiting the Potential for Outdoor Interference

Since the majority of usable signal strength for CBS mobile services from a small cell occurs within 1 km of the transmitter, one might employ directional antennas to focus the available energy within the first kilometer and to mitigate energy propagation outside of that useful area. WiMAX antennas, for example, achieve high gain with low sidelobes. Use of directional CBS antennas on a Durham Hall site would suppress the opportunistic LoS propagation by 30 dB, reducing a signal at -80 dBm to -110 dBm. Additional sidelobe suppression would increase the cost of a site, but when used in the vicinity of a naval radar could suppress interference by another 10 dB to -120 dBm. Since highly directional 3.5 GHz WiMAX antennas have been in production for several years, there are no significant technology challenges to rapid build-out of outdoor CBS small cells that employ directional antennas.

4.8 Indoor Siting

WiMAX measurements in the UK indicate building penetration loss of 9.2 dB with 4.0 dB standard deviation or 90th percentile loss of 14.2 dB[7]. Symmetric propagation from building interior to exterior would meet a loss of 9.2 dB on average and a loss of 5.2 dB 90% of the time. Thus, although indoor siting would suppress radiation causing interference at a distance, it is not a panacea. Indoor siting in a window of a ten story apartment building facing the pier at Norfolk VA 10 km distant could cause significant interference to incumbent naval radar, while siting 1 km distant in a basement apartment with no windows almost certainly would cause no harmful interference. Thus, to successfully avoid harmful interference to incumbents, the three dimensional spatial distribution of energy in frequency and time each may have first order impact on the potential for creating harmful interference.

4.9 Mitigating Harmful Interference

As is generally the case, the FCC is confronted with balancing incumbent protection and providing the economic benefits of new products and services to the public. The NTIA FastTrack report cited in the *Notice* strikes a conservative balance that may protect incumbents but that over-protects shared commercial usage, and that thus may not provide the economic benefits envisioned by the FCC and mandated by the executive branch.

The balance of our comments offers technical methods for mitigating harmful interference to all users. Although these methods are not without cost, the conservatively estimated 4x increase in the size of the CBS market and the 1438 terabits per second of increased subscriber capacity realized will more than pay for the small incremental costs of the technical measures required to conform to strict but highly focused enabling rules that we now recommend.

[7] Belloul et al, "Measurements and Comparison of WiMAX Radio Coverage at 2.5 GHz and 3.5 GHz" IEEE 2009

5 Exclusion Zones

Allied Communications proposes that FCC's CBS rules mandate spectrum measurement by CBS devices, and reporting to SAS, comparable to LTE measurement and reporting by mobile user equipment (UE). With a CBS spectrum sharing database (CSDB), we estimate that 95% of the population could benefit from the 3550 MHz band most of the time and that CSDB improves protection for incumbents compared to the NTIA schema. Exclusion zones of Figure 2 of *Notice* clearly exclude 40% of the US population from CBS, but (as is explained below) actually excludes most early adopters, and at most 20% of the US population would benefit from CBS rule making employing large exclusion zones. Since the 20% of the population includes a majority of counties in the US determined by the Commerce Department to be economically disadvantaged, the market created by CBS is further limited. Rule-making reflective of Figure 1 would increase the percent of US population served by CBS to 95%. A conservative factor of 4x from 20% to 80% represents quadrupling the market, which would attract capital investment to bring economies of scale outlined below. These significant economic benefits may accrue without introducing harmful interference as follows. Allied Communications suggests rules favoring a hybrid SAS architecture, CSDB. that leverages both a database and spectrum sensing.

5.1 Comments on the Existing 3.5 GHz Exclusion Zones

The NPRM specifies the use of this band for the Radiolocation Service (RLS) and the Aeronautical Radionavigation Service (ARNS) (ground-based) on a primary basis for federal use. Footnote G59 states that all federal non-military RLS use of the 3500-3650 MHz band shall be on a secondary basis to military RLS operations. Footnote G110 states that federal ground-based stations in the ARNS may be authorized in the 3500-3650 MHz band when accommodation in the 2700-2900 MHz band is not technically and/or economically feasible.

5.1.1 Small Cell Usage

The FCC's projection of small cell usage is based on first order effects. The values for reduced range are calculated based on the simple free-space path-loss model. We agree that this model demonstrates the most prominent effect of the relationship between frequency and distance in open conditions, with distance decreasing as the square of the frequency which is a free space line of sight propagation model that is not inappropriate for radio propagation between ground and air or for ideal (no multipath) propagation between two radio towers on elevated terrain with no obstructions. This propagation model provides first order effects in ideal circumstances, but is excessively conservative for urban and suburban propagation typical of US eastern and western seaboards with the possible exception of rural Florida where flat terrain may render such a model reasonably accurate. However, such a model is conservative by 30 to 60 dB or more in urban Florida and for more than 60% of the population of the US.

Allied Communications agrees with the FCC that starting with a site radius typical for 850 MHz systems, the distance that would provide the same path loss was calculated to produce the values shown in the NPRM. We also agree that other mechanisms that affect propagation such as clutter and antenna efficiency can also be frequency dependent.

5.1.2 Inapplicability of 850 MHz and WiMAX-based Exclusion Zones

Allied Communications agrees with the FCC that more detailed models that take these effects into account may show somewhat different results. However, we do not agree that generally the relationship should be similar for the following reasons. The 850 MHz band propagates well through foliage and windows of buildings. The 850 MHz frequency corresponds to a wavelength of about one meter. Physical dimensions of reflecting surfaces between 0.25 and 10 meters may reflect incident waves, causing multipath reflections. Large surface areas of buildings may cause significant multipath reflections over relatively long distances. First and second order multipath reflections may cause interference. The heat maps of the Virginia Tech measurement campaign show how these effects are significant in a suburban setting.

5.1.3 Directional Effects Enable Outdoor Priority Usage

High gain antennas require a relatively large physical aperture of on the order of 3 to 10 meters. However, the wavelengths at 3.5 GHz are approximately 10 centimeters. Reflecting surfaces of first order dimensions between 1 and 10 centimeters may cause significant resonant multipath reflections such that typical urban and suburban structures induce Rayleigh-Rice fading, reducing interference. High gain antennas (e.g. on aircraft, vehicles, and buildings) may be on the order of 1 meter in extent, providing many affordable opportunities for directional selectivity in beam forming so as to mitigate interference. Thus, the first order insights regarding the architecture of large cells that one might conclude from measurements and experience with macro-cellular systems at 850 MHz are mostly inapplicable to the technology and commercialization of small cells in the 3.5 GHz band. On the other hand, the 3.5 GHz band is much more like the 2.4 GHz commercial Wi-Fi band.

Hence, we comment with regard to the FCC's question at paragraph 71 regarding indoor vs. outdoor devices that the 3.5 GHz band enables the cost-effective manufacture of directional antennas that may limit radiation in directions causing harmful interference to FSS and radar users. Considering Figure 1, even worst-case omni-directional rooftop deployment of an LTE cell would generally not cause harmful interference to an incumbent user on the ground (e.g. dockside at Norfolk VA) that is more than 1 km distant, particularly given siting facilitated by a SAS database that includes measurements of incumbent signals.

5.2 Radar Exclusion Zone Comments

Allied Communications agrees with the FCC that the federal RLS allocation for military radar systems described above extends from 3500-3650 MHz. We agree that both fixed and mobile high-powered military radar systems on ground-based, shipboard, and airborne platforms operate in this band. We understand that these radar systems are used in conjunction with weapons control systems and for the detection and tracking of air and surface targets, that the U.S. Navy uses the band for a major radar system on guided missile cruisers; and that the U.S. Army uses the band for a major firefinder system to detect enemy projectiles; and that the U.S. Air Force uses the band for airborne radar Station Keeping Equipment throughout the United States and Possessions to assist pilots in formation flying and to support drop-zone training.

We would comment that the map of Figure 2 of the *Notice* does not appear to be representative of the locations of operation. Technology for GAA devices may detect and avoid such signals, providing increased protection to military incumbents. GAA cognitive small cells may embody basic automatic gain control (AGC) and related behavior adjustments upon recognition of AGC features indicative of radar operation.

In addition, such GAA protection offers the military additional opportunities to use the 3550 MHz band in the future. Some future military aircraft may benefit from the use of the CBS band. Without GAA device detection of radar, the contours of Figure 2 of the *Notice* may render such usage in the interior of the US impractical as CBS small cells are deployed outside of the incumbent exclusion zones along the coast. Thus, a future aircraft transiting the US, e.g. for training purposes, may illuminate a relatively large expanse of the CBS spectrum. Since radar systems employ high-gain antennas with high instantaneous pulse power, CBS devices could reliably detect such illumination. CBS devices could generate interference in the form of apparently Doppler-shifted clutter (also known as hot clutter). Such clutter may be regarded as harmful interference to a future radar. However, known signal processing techniques may suppress the hot clutter. A spectrum use policy for CBS devices detecting radar to cease to transmit for a period of time defined in an SAS CSDB upon detecting rapid AGC changes may provide a dynamic contour for the protection of a future military incumbent. The resulting dynamic contours would move with the future military aircraft. Thus, GAA cognition in the form of radar detection and avoidance would enable the military to continue to employ the 3550 MHz band for future radar systems with a reasonable expectation that CBS devices would defer to radar as a protected incumbent. In order for this approach to have high confidence of dynamic protection of unanticipated incumbents, CBS devices may need a degree of tamper resistance.

5.3 Fixed Satellite Service Exclusion Zone Analysis

Allied Communications accepts the FCC's use of the 150 kilometer exclusion zone imposed on operations in 3650-3700 MHz as a starting point. However, dynamic exclusion zones enabled by RSSI reporting to a SAS CSDB as recommended above may provide greater usage of the spectrum without introducing harmful interference as explained below regarding asymmetric interference of FSS with respect to CBS.

5.4 Comments Regarding Dynamic Contours

Suppose the FCC adopts rules that allow indoor usage of CBS devices provided that CSDB as recommended above estimates 100 dB of isolation between a GAA transmitter and the nearest incumbent. Apartment buildings present typically 10 dB of protection per exterior wall with 3dB for many types of windows and 3 dB for some types of walls. Absorption and dispersion of Figure 1 above may be included in CSDB estimation tool. Thus, a ground floor apartment in Norfolk, VA located within 1 km of a Navy ship may present 100 dB of isolation of a CBS transmission from the incumbent. A CSDB may measure such losses given CBS device RSSI reporting with location based, e.g. on address and apartment number. With high fidelity radio propagation prediction and validation capability, CSDB could establish addresses, floor levels, and apartment numbers that would provide the required 100 dB of isolation. Hence, dynamic contours could shrink from the 45-350 km contours of the NTIA FastTrack report of Figure 2 to under 5 km, with many potential users within 2 km of an incumbent such as a Navy ship at dock. There would be no exclusion zones along the coastal areas that could be illuminated by such ships, so the state of Florida and most of the East coast and California no longer would be exclusion zones. Thus, an estimated 95% of the population of the US might enjoy CBS usage and thus would qualify as a market.

6 Asymmetry of Interference

Depending on the constituency, concerns over interference in spectrum sharing environments may be concerns that incumbent systems interfere with mobile broadband systems, or vice versa. An important thing to keep in mind is the highly asymmetric transmit powers and antenna gain, cellular systems experience asymmetric interference from radar systems as noted in the *Notice* at paragraph 59. Allied Communications recommends that FCC rule-making leverage the benefits of this physical asymmetry for CBS devices and for SAS.

6.1 Interference Analysis for Radar

Comments of this section apply to the *Notice* at paragraphs 5, 6, 18.21, 26, 59, 66, 67, 90, 93, 96, 103 (regarding databases), 110, and 112-123.

The primary observation regarding the asymmetry of radar interference with communications is the very high instantaneous power of pulsed radar with pulses that may be less than 1 ms in duration transmitted at very high power (kW) and with high gain (20-40 dBi) resulting in such high RSSI that a communications receiver's automatic gain control (AGC) will be captured, resulting in the loss of received communications signal during AGC recovery which may be many milliseconds. Because of the high power, a radar pulse can capture the CBS devices' AGC, causing an LTE device to lose multiple sub-frames or frames of data. LTE's hybrid automatic repeat request (HARQ) would cope with such interference via reduced data rate. A multiband multimode CBS device with Wi-Fi and TVWS capabilities might change bands or modes into bands that may become crowded because of the radar forcing users out of CBS.

Tests done by the US Navy between a naval radar platform and a WiMAX system operating in the 3.5 GHz band[8] corroborate this conclusion. Regardless of operating mode, typical radar pulse widths are shorter than the OFDM symbol time for an IEEE 802.16-2004 system, and the radars have a duty cycle of roughly 5%. Consequently each pulse can, at worst, case a bit error rate of 50% on 5% of the OFDM symbols, or an overall bit error rate of 2.5% which can be readily addressed through forward error correction. However the Navy test yielded packet loss rates of between 40% and 90% depending on the exact experiment parameters. This demonstrates higher-level impacts from high peak pulse power, such as the aforementioned AGC capture. These issues can be readily addressed on the victim communication systems through impulsive noise filters that protect AGCs from radar pulses.

While the channels themselves may be symmetric, the peak radiated powers differ by, for example, 60 dB. Thus when developing exclusion zones, it is important to understand who is being protected from whom. Consider an LTE system which can detect a radar pulse if that pulse has 10 dB of SNR, and a radar system that conservatively receives interference with -10 dB I/N. The LTE system has a 20 dB detection/interference disadvantage, but this is more than overcome by the 60 dB differential in transmission power. The consequence is that an LTE system will *always* be able to detect pulses from a radar with which it could potentially interfere and use this knowledge to adjust its operating behavior.

[8] K. Carrigan, L. Cohen, R. Ford, L. Lieb, A. Light, L. Pham, J. Smith, J. Warner, J. Wood, "Interim Assessment of AN/SPY-1 to WiMAX Electromagnetic Capability: Assateague-Wallops Islands Field Test", July 2007.

6.2 Interference Analysis for Fixed Satellite Service

Comments of this section apply to the *Notice* at paragraphs 8, 12, 13, 18, 23, 24, 27, 28, 54, 65, 69, 92-94, 96, 102, 105, 109, 110, 124-127, 130-133, 137, 138, and 145.

Allied Communications would comment that such exclusion zones do not take into account the beneficial effects of CSDB in SAS. According to our recommendations for rule making delineated above, mobile CBS devices will measure RSSI and report features useful for signal classification of received signals. An appropriate tier of CSDB may then classify the emission as originating from FSS. Frequency division duplexing establishes a hidden node problem in which the FSS ground station is receiving in the CBS band from a satellite via a large antenna with potentially significant ground-facing sidelobes. CBS device transmission into such sidelobes introduces harmful interference. However, high performance commercial radio propagation tools achieve very accurate prediction of RSSI over large geographic areas. A CSDB may calibrate such a high fidelity model by comparing predictions to measurements made by CBS devices. Accordingly, the contours for CBS usage may be gradually extended from a 150 mile exclusion zone towards an existing FSS. An FSS may register complaints into the CSDB that would result in automatic termination of emissions of CBS devices causing interference.

Therefore, FCC rule-making should allow CBS devices to encroach on a 150 mile exclusion zone provided that (1) the CSDB includes the FSS, (2) the CSDB incorporates a validated terrain model of the 150 mile region of operation of the FSS, (3) the CSDB incorporates a high fidelity RSSI propagation tool, (4) a CBS device encroaching the 150-mile exclusion zone is always on-line or has turned itself off and (4) the device incorporates circuitry that will disable operation on frequencies determined by CSDB, e.g. in response to an automatically generated complaint by the FSS to the CSDB regarding a given frequency, location, and time.

6.3 Achieving Quality of Service

Again with reference to Figure 1, the heat map corresponds to an LTE signal of 41 dBm. Typical LTE equipment available today would allow the identification of five 20 MHz CBS channels in the 3550 MHz band. Carrier aggregation (CA) of LTE advanced entails the simultaneous use of multiple channels for a given user equipment. LTE base station equipment now being tested for commercial evolution during 2013-2015 includes CA. Application of CA in a CBS allocation with signal intensity corresponding to the heat map of Figure 1 provides gigabits per second of data rate per user within 500 m of Durham hall, i.e. where RSSI is above -70 dBm. Multi-sector and MIMO antennas multiply the spectrum availability via spatial reuse, providing these benefits to multiple users at once, enhancing quality of service.

7 CBS Market Structure and Economies of Scale

The *Notice* specifically requested comments regarding costs and benefits. Specifically at paragraph 51, the Notice requests "commenters should provide specific data and information, such as actual or estimated dollar figures for each specific cost or benefit addressed, including a description of how the data or information was calculated or obtained, and any supporting documentation or other evidentiary support." This section therefore offers comments regarding the costs and quantitative benefits with respect to the structure of a potential CBS device market with and without Allied Communications' recommendations. At *Notice* Figure 2, 60% of the US population appears is excluded from the CBS market. While it is true that taken at face value, the exclusion zones preclude CBS usage in a land area with 60% of the US population, the resulting size of the CBS market would not be 40% of the population of the US, in part because of market structure and missing economies of scale.

7.1 Market Structure Use Cases

Consider the following alternative use cases. Suppose it takes $10M and 9 months to introduce a CBS product such as a small eNB. There are 311 million people in the US, for a total market of approximately 42 million households. Suppose an investor projects a 10% adoption rate (4.2 million users) and first year market penetration of 5% (210k sales). Suppose further that costs of capital equipment, recurring engineering, marketing, subsidies, and distribution are four times the R&D cost of $10M. The resulting $50M development and first year deployment costs would be amortized over 210,000 units for a cost of $233.76 per unit. Suppose further that parts cost $50 and assembly in the US costs $50 per unit for a per-unit cost of $100. The price point of initial CBS devices including cost plus amortization would be $333.76, resulting in a price range of $350-500. This may not be unreasonable for early adopters such as citizens' broadband radio enthusiasts. However, the expectations of at most 40% of the US market and of that market includes only Chicago and Texas as relatively high-end spectrum usage markets, but that specifically excludes the NYC megalopolis, all of Florida, and California, it will be difficult to obtain financing and few entrepreneurs will be attracted to the market. Furthermore, the remaining 40% of the US population includes over half of the counties determined by the Census to be economically disadvantaged. Thus one or two major equipment incumbents may be willing and able to risk market entry.

However, Allied Communications recommendations enable the projection of larger markets resulting in substantially different economics. Suppose FCC rules allow indoor usage of CBS devices and CSDB demonstrable 100 dB of isolation between a GAA transmitter and the nearest incumbent as described above. An estimated 95% of the population of the US might qualify as a market. Devices providing Wi-Fi, TVWS, and CBS might be deployable to 100% of the population of the US with 95% able to use the CBS band as authorized by a dynamic CSDB with closed loop feedback to the devices. Given such attractive economics, applying the same cost models as above yields a total market of 29 million families, 3 million of which might be available for first year amortization, for $16.95 of amortized cost vs $233.76. In addition, the larger quantities attract greater capital investment so that manufacturing learning curves reduce the cost to manufacture the units from $50 per unit to $10 within the first three years while the devices remain profitable at a sales price of $99.95.

Clearly, the exact prices are notional and to not take global economies of scale, advantages in adapting WiMAX to CBS, and many other factors. However, these use cases are offered to stimulate further consideration the Commission regarding such potentially nonlinear and multiplicative effects of rule-making.

7.2 Quantifying the Social Benefit

From a related perspective, one may characterize societal benefit in terms of averting the spectrum crunch, which is a shortage of data rate for mobile devices. One may project market size impact on the peak new capacities offered under different sets of rules. Table 1 shows the contribution of Allied Communications recommendations for rule making comparing the rules of the current notice, with large exclusion zones with the dynamic contours of a secure CSDB (column 3).

The table measures societal benefit in the increase in digital communications capacities during peak loading, such as at peak hour of the commercial day or during a public safety emergency. Under current rules, only 40% of the population of the US is a viable CBS market. Since the most disadvantaged counties are in the viable population, the table projects only 5% penetration, which is one small cell for every 20 people. With Allied Communications' recommended rule making, the marked is over twice as large, so the investment is larger and proportionally more people benefit, for penetration level of 10%, one small cell for every 10 people. First year deployments would be lower under proposed rules because of higher costs and higher because of commercial marketing and sales outlets opened by lower costs for differential first year unit deployment rates of 1% of market vs 5% of market. If each cell provides 144 Mbps of additional peak capacity, then under Notice rules, there would be an additional 8.9 Terabits per second of added peak capacity. However, with Allied Communications' recommendations, there would be 216 Terabits per second, an increase of over 200 Terabits per second, a factor of 24x.

Table 1, Societal Benefit of Proposed Rules vs. Allied Communications' Recommended Rules

CSDB contribution to peak data rate				
310000000	population of US			
186000000	pop excluded	50000000		
124000000	Pop remaining	260000000		
100%	Time excluded	20%		
186000000	Time pop excluded	10000000		
124000000	Viable pop	300000000		
40%	% viable	0.967741935		
5%	Penetration %	10%		
6200000	Market size	30000000	4.83871	ratio
1%	First Year	5%		
62000	Units deployed	1500000		
0.144	Peak data rate	0.144		
8928	Capacity increase Gbps	216000		
8.928	Capacity incr Tbps	216	24.19355	ratio
		207.072		

The net effect, Allied Communications would comment would be that our recommendations including in rule-making a SAS a dynamic CSDB with fine grain space-time resolution and device feedback; and with enhanced security would transform CBS from a small niche product that is not very attractive into a large market attracting investment and benefiting from manufacturing learning curves, resulting in spectrum availability yielding additional hundreds of terabits per second of peak wireless capacity to the vast majority of US homes, businesses, and enterprises.